THE 1997–8 EL NIÑO AND THE GALAPAGOS TORTOISES *GEOCHELONE VANDENBURGHI* ON ALCEDO VOLCANO, GALAPAGOS

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SUMMARY

Body mass changes, mortality and nest and egg loss of the Galapagos tortoise *Geochelone vandenburghi* were studied on Alcedo Volcano, Isabela Island, before, during and after the El Niño event of 1997–8. The results suggest that fewer tortoises in the pre- and post-Niño periods gained body mass than lost, while during the El Niño event itself the tortoises gained mass. Before and after the El Niño, there was no mortality attributable to flooding in the ravines on the slopes of the volcano, but during the El Niño event 36 tortoises were found dead in the ravines. This is < 1 % of the total population. Nest and egg loss due to fungus damage was low (<10 %) in the pre- and post-Niño periods, but during the event a significantly higher proportion (80 % of 76 eggs) were destroyed by fungal infection.

RESUMEN

Cambios en la masa del cuerpo, mortalidad y la pérdida de huevos de la tortuga de Galápagos *Geochelone vandenburghi* fueron estudiados en el Volcán Alcedo, Isla Isabela, antes, durante y después del acontecimiento El Niño de 1997–8. Los resultados sugieren que las tortugas en el pre- y post-Niño incrementaron el peso y más individuos disminuyeron el peso. Durante El Niño, más tortugas incrementaron el peso y menos animales disminuyen el peso. Antes y después de El Niño no hubo mortalidad por causa de inundación en las encañadas en las faldas del volcán, pero durante el acontecimiento El Niño se encontró 36 tortugas muertas en las encañadas. Esta fue estimada en < 1 % de la población total. Daño a los nidos y huevos por hongos fue baja (<10 %) en los periodos pre- y post-Niño, pero durante el evento una cantidad significativamente mayor (80 % de 76 huevos) fue destruido por infección de hongos.

INTRODUCTION

Galapagos tortoises *Geochelone* spp. are the dominant native herbivores in the Galapagos archipelago. On Alcedo Volcano, Isabela Island, occurs the largest remaining population, *G. vandenburghi* (Fowler 1983, de Vries 1984, Enriquez 1984, Cayot 1987), estimated at between 10,000 and 12,000 individuals (Márquez *et al*. 2004). Between 1990 and 2006 the tortoises of Alcedo suffered competition for food from an abundant population of feral goats *Capra hircus* (Márquez *et al*. 2004), although an eradication program begun in 2004 had almost completely eliminated goats from Alcedo by early 2006. The effects of this competition might be exacerbated by natural phenomena such as extreme drought or extremely rainy years, such as those caused by an El Niño Southern Oscillation event. El Niño is an atmospheric-ocean phenomenon associated with heavy rains in the eastern Pacific, where it is often followed by a dry year (La Niña), both of which can affect the fauna and flora of Galapagos (Snell & Rea 1999, Cayot 1985). However, the effect of El Niño on the Galapagos tortoises has not been documented.

The present report evaluates a possible effect on the tortoises of Alcedo Volcano by the strong El Niño event of 1997–8, via effects on body mass, mortality from drowning and injury from falling into rushing waters in ravines, and loss of eggs as a result of contamination by fungus in the nests. We compare the body mass of the tortoises, egg losses and mortality in the population of the Alcedo tortoises for three two-year periods: prior to the El Niño event ("Pre-Niño" 1995–6), during the El Niño event (1997–8), and following it ("Post-Niño" 1999–2000).

METHODS

Study area

Alcedo Volcano is located in the centre of Isabela Island, with a maximum elevation of 1128 m and an area of 798 km^2 (Black 1973). It is principally covered with arid woodlands, although with areas of more dense and humid vegetation on the higher slopes, and with some grassland near the crater edge. Introduced mammals that shared habitat with the tortoises and compete with them included goats and donkeys *Equus asinus*. Black rats *Rattus*

rattus and feral cats *Felis catus* also occur in the area and are predators on newly-hatched tortoises. Alcedo is the only Galapagos volcano that has a reproductive population of tortoises on the interior, edge and flanks of the crater.

Tortoise marking and monitoring

Tortoises were individually marked with permanent branded numbers on the fourth left plate and with a passive integrated transponder (PIT) tag injected under the skin of the left hind leg. The tortoises were monitored twice per year from November 1995 to November 2000, and at each visit, tortoises that had not been identified previously were marked. Over the study period, 961 tortoises were marked and 540 of them relocated and re-measured. Monitoring transects were established and searched during each survey on the east slope, and on all of the crest and interior of the crater.

Information collected

The locations of all tortoises encountered, whether alive or dead, and all tortoise nests, were recorded using Global Positioning System receivers and mapped using a Geographic Information System. All live tortoises encountered were sexed and aged (male, female or juvenile) as far as possible (the sex of young tortoises cannot be determined; therefore, they were counted as juveniles). They were weighed using a tetrapod frame and an electronic balance of capacity 1 t.

Tortoises found dead were divided into three categories of likely mortality:

a) Accidental death by falling, with the carapace semi-destroyed but the remains not dispersed (Fig. 1).

b) Accidental death by floodwaters (tortoises falling into or being trapped in ravines filled with waters from heavy rains), with the carapace disarticulated and remains dispersed along the ravines.

c) Death with the carapace intact, with no parts broken, its keratin plates in place and upright (plastron down) at the presumed site of death, the cause of mortality being unknown but likely not from falling or flooding. This included tortoises found dead at the summit of the crater (Fig. 2).

The carapace of a tortoise was considered destroyed when remains were scattered, or it was broken at the junction of carapace and plastron or frontally or posteriorly. The remains were classified as male, female or juvenile. Although tortoise poaching occurs on Isabela Island, none of the tortoise mortality found during this study was a result of humans killing the tortoises.

Search for dead tortoises in ravines

Six ravines were selected for repeated intensive search for tortoise remains. A transect of 300 m was established in each ravine, for a total of 1.8 km total transect length. The transects were searched each time the tortoises were monitored. All tortoises found dead on the transects were evaluated as described above.

Tortoise nests and eggs

Tortoise nests were excavated, as part of the captive-rearing program carried out by the Galapagos National Park and Charles Darwin Research Station. Eggs were examined to determine if they were broken, infertile, or had been killed by fungus. Signs of fungal infection included the egg exterior being covered by fine, soft, gray hairs and its interior showing dark black spots. Eggs were determined to be infertile when their exterior appeared normal, but following incubation (as part of the captive-rearing program) the egg failed to hatch and proved to contain no embryo. Eggs that subsequently hatched in the captive-rearing program incubators were considered normal.

Figure 1. Partially destroyed carapace of a tortoise, possibly killed in a fall or by being washed down a ravine by flood waters (live juvenile tortoise walking in the foreground).

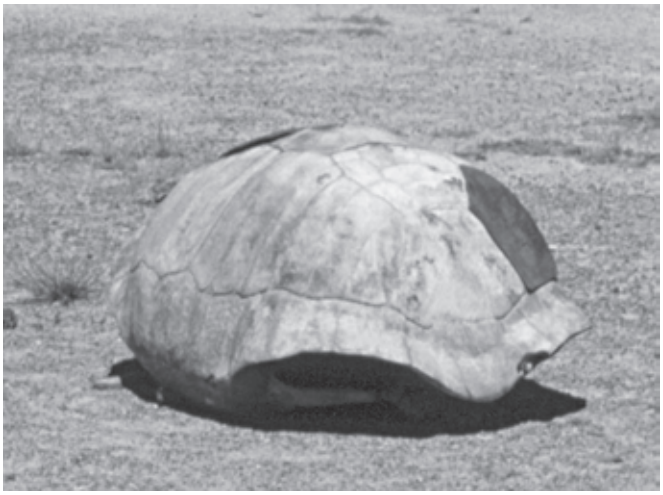

Figure 2. Intact carapace of a tortoise that died of natural but unknown causes.

Study periods

The Pre-Niño study period encompassed three monitoring trips, 9–20 November 1995, 23–29 May 1996 and 26 November to 3 December 1996. Rainfall during this period at the Charles Darwin Research Station weather station in Puerto Ayora, Santa Cruz Island, was 251.7 mm, and the average temperature was 23.2°C. During the El Niño event of 1997–8, monitoring trips were made on 4–9 May and 18–24 November 1997, and 18–25 May and 9–17 November 1998. During the El Niño, the rainfall was 1703.8 mm, and the temperature was 25.6°C. In the "Post-Niño" period, monitoring trips were made in 12–19 November 1999 and 4–9 November 2000. During the Post-Niño, rainfall at Puerto Ayora was 166.1 mm and the temperature was 23.4°C.

RESULTS

Changes in body mass

During the Pre-Niño period 10 of 34 (29%) tortoises recaptured showed an increase in body mass of 1–10% (Table 1), whereas the remaining 24 (70.59%) showed a decrease in body mass of 1–15%, in relation to their mass in November 1995. During the El Niño event, 39 of 50 (78%) of the tortoises increased their mass over their initial (Nov 1995) weight, and the remaining 11 (22%) decreased. In the Post-Niño 17 of 28 (61%) tortoises decreased their mass with respect their mass over their initial weighing, and 11 (39%) increased. The proportions showing change in mass in different directions were significantly different between the three periods (c^2_2 = 22.3, $P < 0.0001$).

Comparing the three periods, the groups of tortoises that lost and increased mass before or after the El Niño event were not different with regard to average mass lost or gained among the three events (factorial ANOVA, F = 9.48, $P > 0.05$). In the Pre-Niño and Post-Niño, the average changes in mass were similar (Table 1), while during the El Niño event the average value for change in mass was greater, although not significantly so ($t_{82} = 0.71$, $P > 0.50$; Table 1).

Mortality of tortoises

In the two years of the Pre-Niño period (1995–6), dead tortoises with destroyed carapaces were not recorded either in the interior or along the 300 m of transects in any of the ravines surveyed. During this period four dead tortoises but with the carapace intact were recorded outside the six ravines. During the two years of the El Niño event (1997–8) at least 36 dead tortoises (29 adults and seven juveniles) with the carapace destroyed were recorded, all in the interior of the six ravines. No dead tortoises were recorded outside the ravines during the El Niño. During the Post-Niño (1999–2000) no recently-dead tortoises were recorded inside the ravines, but nine dead tortoises with intact carapaces were encountered outside the ravines. The number of dead tortoises by period and site were different between the Pre-Niño, El Niño, and Post-Niño ($c^2_5 = 26.9$, $P < 0.001$). The number of dead tortoises during the El Niño event is < 1 % of the total population.

At El Geiser on the interior slope of the volcano crater at *c*. 970 m altitude, on two occasions tortoises were observed to fall, with the impact destroying the carapace and the tortoise dying within a few minutes. At this site, five mortalities due to falls were recorded in the Pre-Niño, nine due to falls during El Niño, and four due to falls in the Post-Niño.

Nests and eggs destroyed

During the El Niño period, 11 tortoise nests containing a total of 76 eggs were excavated, of which 61 eggs (80 %) were decomposed through damage by fungus. In the Pre-Niño, five nests containing 40 eggs, and in the Post-Niño four nests with 32 eggs were excavated, but in none of those nests were the eggs decomposed or showing evidence of fungus. The numbers of damaged and viable eggs in the three events were significantly different (c^2_4 = 80.7, $P < 0.0001$). During the El Niño period, broken eggs were discovered dispersed over approximately 1 ha at the end of one of the ravines on the southwestern interior of the crater. These eggs were presumably destroyed when washed down from the ravine. In the Pre-Niño and Post-Niño at the same nesting site, no damaged eggs or eggshells were seen.

DISCUSSION

Changes in body mass

Before the El Niño an equal number of tortoises increased mass as decreased, while during the El Niño and Post-Niño, the number that increased body mass was greater than the number that decreased. The averages of increase and decrease are not different among the three events. This suggests that the El Niño and Post-Niño are favorable

Table 1. Changes in body mass (kg) of Galapagos tortoises *Geochelone vandenburghi* during Pre-Niño, El Niño and Post-Niño periods on Alcedo Volcano.

	Mass gain in tortoises showing increased mass			Mass loss in tortoises showing decreased mass			
	mean ± SD	Range	n	mean ± SD	Range	n	n Total
Pre-Niño (1995–6)	18.28 ± 16.55	1.26–43.54	10	11.74 ± 12.06	0.2–47.4	24	34
El Niño (1997–8)	21.49 ± 22.63	1.0–93.99	39	14.44 ± 14.17	1.25–54.71	11	50
Post-Niño (1999–2000)	18.06 ± 17.02	0.1–66.84	11	11.07 ± 7.21	0.2–27.75	17	28

for gain in body mass to the majority of tortoises, while in the Pre-Niño 71% of the individuals are benefited by mass gain and the rest maintain their mass or decrease. The maintenance of an elevated mass after the El Niño probably resulted from the exuberant vegetation that grew as a result of the El Niño event, which provides abundant food for the tortoises. The tortoises increase their body mass when there is an abundance of food and water during and for several years following the El Niño event. According to MacFarland *et al*. (1974), Fowler (1983), Beaman (1985), Cayot (1985), and T. Fritts (pers. comm.), during the 1982–3 and 1997–8 El Niño events, tortoises gain body mass and size when El Niño events occur and immediately afterward.

The physiological and behavioral factors involved in changes in body mass in the tortoises are not known, but are thought to include: 1) a capacity to self-regulate body mass, in accordance with the availability of food and environmental conditions; 2) egg-laying (females); 3) reduced activity (including foraging) when faced with reduced availability of succulent vegetation, reduction in weight of body water, and poor health. They increase mass when they are foraging constantly. Adult tortoises from the islands of Pinta and Española changed mass over four years in captivity (unpubl. data), probably not as the result of El Niño nor of lack of appropriate food, but reflecting natural physiological changes that occur in these animals.

Mortality of the tortoises

At least 36 adult male and females and juvenile tortoises were found dead in the six ravines which were regularly monitored, possibly as a result of flooding caused by heavy rains. To cool off, tortoises partially submerge themselves in pools of water, usually found in the bottoms of ravines. They may also sleep in ravines, and are not able to escape when the waters begin to rise. It is thought that some of the tortoises were killed when being washed down the ravines and smashed against rocks. Others were probably killed by falling on material loosened by the rains, down slopes and into the ravines. In other populations tortoises have been found dead as a result of bacterial septicemia and intestinal parasites (unpubl. data, Snell & Rea 2000). In captivity on Santa Cruz Island, tortoises have died from pneumonia, infections of the intestinal tract or respiratory system, accidental overturning, and injuries resulting from moving (unpubl. data). In tortoises that die of natural causes, particularly as a result of disease, the carapace is not damaged immediately, although it may disintegrate into pieces more than a year after the death of the animal.

Nest and eggs destroyed

On Alcedo Volcano, some female tortoises lay in nests within or alongside the ravines, where they can be destroyed by floodwaters. Flooding damage probably only affects tortoise populations nesting on the steeper slopes of volcanoes on Isabela Island. There was also an increase in fungal infections in the clutches during El Niño years.

ACKNOWLEDGMENTS

We sincerely thank the Charles Darwin Foundation Inc., Galapagos Conservation Fund and Frankfurt Zoological Society for funds that supported this project. We thank the Galapagos National Park Service for permitting the study. We thank those who have helped in the field and collecting data: Sandra Landázuri, Alizon Llerena, Alberto Jaramillo, Edison Encalada, Fernando Valladares, María de Lourdes Torres, Dorsey Burger, Kenny Gililan, James Gibbs and Daniel Valdivieso, and the GNP personnel Víctor Carrión, Nelson García, Máximo Mendoza, Klever Aguilar, Bolívar Guerrero, Manuel Masaquisa, Fredy Mosquera, Franklin Gil, Hector Serrano and Ángel Palermo. This paper is Contribution number 1086 of the Charles Darwin Research Station.

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